

Bringing Fusion Research into Focus

T'S no mystery that high-powered laser systems such as the National Ignition Facility (NIF) are at the forefront of scientific discovery—especially in the field of high-energy-density physics. What has puzzled researchers, however, is developing a method to accurately manipulate certain properties of the megajoule-level laser beams to better enhance inertial confinement fusion (ICF) research.

The continuous-phase-plate (CPP) optics system developed by a Livermore research team offers an elegant solution to this challenge. The team, led by chemist Joe Menapace of the Laboratory's Chemistry, Materials, and Life Sciences Directorate, received an R&D 100 Award for the novel technology. Livermore has partnered with Zygo Corporation of Middlefield, Connecticut, and QED Technologies of

Rochester, New York, to make the new technology commercially available.

To create the best environment for achieving nuclear fusion with a high-powered laser such as NIF, researchers must precisely characterize and control each beam's illumination at the target plane. With Livermore's CPP optics system, they can manipulate a beam's shape, energy distribution, and wavefront profile. This level of control will allow scientists to design rigorous fusion experiments that examine details of phenomena such as how the universe began and how nuclear weapons age.

Behind the Plate

Continuous phase plates are large-aperture diffractive optics that can adjust and fine-tune a laser beam to a prescribed size and shape while maintaining the

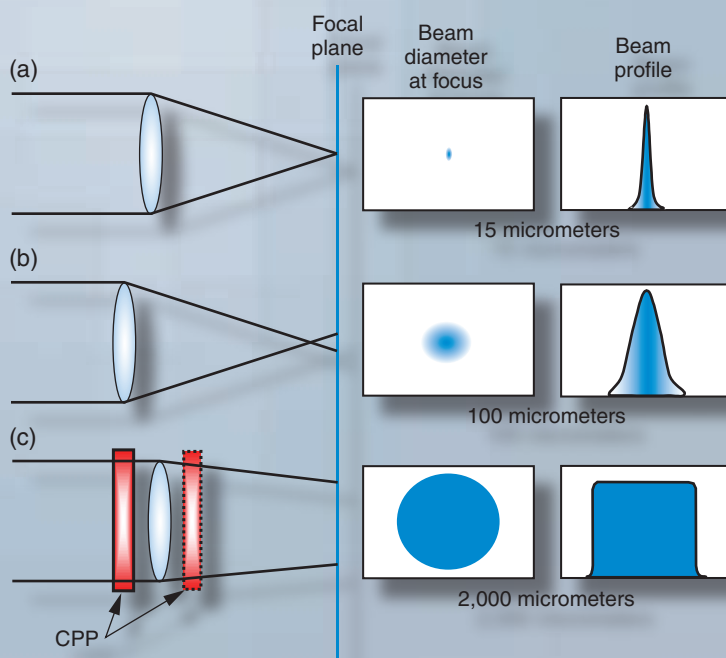
coherent properties of the laser light. CPPs work with a focusing element, such as a lens, to define a beam's characteristics.

For example, using only a lens, researchers can focus a 360-millimeter-square laser beam to a spot about 15 micrometers in diameter on the target. The focused beam has a high intensity, but because of its small diameter, it cannot illuminate a large area (up to 1 millimeter in size) with coherent light. In addition, the lens-only configuration results in nonuniform illumination of the target. The spot size can be increased to about 100 micrometers by defocusing the lens. However, this process does not produce the optimal beam shape for ICF experiments, and the beam's intensity diminishes away from the center.

Introducing a CPP into the optics chain solves this problem. CPPs take advantage of the apparent bend in a light wave when it encounters a topographic change on an optical surface. To design CPPs for NIF, Menapace's team uses a computer program to generate a continually varying phase profile that will achieve the required energy profile. The topographic changes are then imprinted onto the surface of defect-free fused-silica optics. The variations in surface topography perturb the wavefront of the incoming laser beam either before or after the beam passes through the final focusing element. This process yields a beam footprint at the target with the desired characteristics.

A CPP can be designed to convert a square or circular laser beam to an elliptical or circular spot with the required dimensions. Other spot shapes are possible, including triangles, squares, and closed polygons.

A laser beam can be controlled with a lens (a) focused to its diffraction limit, (b) moved out of focus, or (c) combined with Livermore's continuous-phase-plate (CPP) optics system. CPP optics allow researchers to control a laser beam's size and shape and maintain its uniformity across the target area.



With Energy to Burn

Researchers must tailor CPP optics for a particular experiment. For example, in ICF experiments, NIF laser beams will focus on a tiny gold hohlraum that surrounds a sphere filled with gaseous and liquid or solid deuterium and tritium. The laser shot creates very high-energy-density matter, and the generated x rays blow off from the capsule surface, compressing the fuel sphere. Under these extreme conditions, the fusion fuel core implodes, ignites, and generates thermonuclear burn, yielding many times the input energy. In such a scenario, CPPs would be designed to spread the laser energy uniformly over the hohlraum interior, producing a symmetric implosion. The optics also shape the initially square laser beams into elliptical spots, which, because of their angle of entry, project as circles on the hohlraum walls.

In ICF applications, CPPs control each beam's spot size so light does not impinge on critical components in the target area. In addition, they help maintain a beam's projection angle and keep its energy uniform as it illuminates the target. CPPs also eliminate high-intensity areas, which can cause hydrodynamic performance to deteriorate.

Magnetic Attraction

Menapace's team designed the highly precise optics so they will survive extremely powerful laser pulses without being damaged. CPPs also do not add unwanted distortion to the focused laser beam.

To manufacture optics to the extreme tolerances required, the team developed a magnetorheological finishing (MRF) technology for polishing surface topography onto optical surfaces. This method pairs an



The project team for Livermore's continuous-phase-plate optics system (from left): Christopher Haynam, Gregory Rogowski, Jeff Atherton, Joe Menapace, Pete Davis, Jack Campbell, and Sham Dixit.

electromagnet with a magnetic fluid that contains microscopic abrasive particles. A computer program determines how the electromagnet and fluid interact to imprint the desired topographic structure on the optics. The MRF system, which combines interferometry, precision equipment, and computer control, is a key technology for CPP optics. "Traditional methods for polishing optics are more of an art than a science," says Menapace. "Imprinting varying topographies is simply not possible with those techniques. The MRF approach is pushing the technological limits of optical polishing, allowing us to make not only more precise parts but also more complicated optics."

And these more complex optics are enabling systems that could never have

been imagined with current technology. "NIF is just one example," says Menapace. "Using traditional techniques to develop optics for this powerful laser was an impossibility. We had to create a new technology to make the system work."

—Maurina S. Sherman

Key Words: continuous-phase-plate (CPP) optics system, inertial confinement fusion (ICF), laser optics, magnetorheological finishing (MRF), National Ignition Facility (NIF), R&D 100 Award.

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